TRACKED GULLS HELP IDENTIFY POTENTIAL ZONES OF INTERACTION BETWEEN WHALES AND SHIPPING TRAFFIC

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Received 10 May 2023, accepted 28 June 2023

ABSTRACT

CIMINO, M.A., WELCH, H., SANTORA, J.A., KROODSMA, D., HAZEN, E.L., BOGRAD, S.J., WARZYBOK, P., JAHNCKE, J. & SHAFFER, S.A. 2024. Tracked gulls help identify potential zones of interaction between whales and shipping traffic. *Marine Ornithology* 52: 61–72.

Seabird-vessel interactions are often studied through the lens of fisheries bycatch, but seabirds encounter many watercraft types. Western Gulls *Larus occidentalis* breeding on the Farallon Islands (California, USA) have a foraging domain that encompasses both shipping lanes and productive fishing grounds, resulting in ample opportunities for vessel encounters. Previous research showed that these Western Gulls can serve as ecosystem indicators because their foraging behavior is linked to ocean prey conditions, and because their foraging grounds overlap with that of Humpback Whales *Megaptera novaeangliae*, which can make prey accessible. Because ship strikes and entanglement in fishing gear are concerns for whales in this region, we investigated gull-vessel interactions as a proxy for identifying whale ship-strike risk by assessing the geographical overlap between GPS-tracked gulls and vessels using the Automatic Identification System. During 2014–2019, 40% of tracked gulls encountered a vessel, resulting in 85 encounters. Gulls mostly encountered cargo ships and tug/pilot boats, mainly within the shipping lanes (79%). Over 30% of these encounters co-occurred with gull foraging events, and most encounters were situated within shipping lanes (80%). Moreover, most gull foraging events began before the vessel encounters, which appeared to interrupt gull behavior. Interannual variability of encounters was mainly related to gull foraging locations: during years of high oceanic productivity, foraging more frequently occurred at sea rather than nearshore or on land, leading to more encounters with ships. This study builds on work that documented overlap between Humpback Whales and Western Gulls but did not test whether foraging gulls encountered vessels. We found that some vessel encounters coincided with gull foraging events; from that, we suggest that the real-time processing of seabird tracking data could provide additional information on whale distribution (which is more difficult to study) within regions of high ship-strike risk and could be included as another tool for dynamic ocean management.

Key words: indicator, ship strike, Western Gull, Humpback Whale, AIS, vessels, biologging

INTRODUCTION

Wildlife populations have been heavily impacted by human activities. While some ecosystems remain more wild and less impacted than others (McCauley *et al.* 2015, Grémillet *et al.* 2018), increasing use of marine resources and the expansion of coastal human populations will have significant consequences for ocean environments (Jackson *et al.* 2001). Many human-animal interactions are directly or indirectly harmful, but human activities can also create foraging opportunities or new habitats for scavengers (Oro *et al.* 2013, Ripple *et al.* 2014). Interactions with fishing boats and other types of vessels pose some of the greatest risks to seabirds and other marine populations, and in many cases, a paucity of information on when and where these interactions occur precludes effective mitigation actions (Schwemmer *et al.* 2011). For example, fisheries bycatch, entanglement in fishing gear, and ship strikes are common sources of injury or mortality for seabirds, sea turtles, and marine mammals (Moore *et al.* 2009, Carretta *et al.* 2015, van der Hoop *et al.* 2015, Valdivia *et al.* 2019). Sentinel species (Hazen *et al.* 2019) and derived indicators can provide information on changing ecosystem processes that would otherwise be difficult to assess. These assessments are gaining importance as anthropogenic impacts on marine ecosystems are increasing rapidly.

Human activities continue to be one of the leading causes of whale mortality despite ongoing management efforts. Hence, there is a continued need for additional indicators of risks to whales (Davies & Brillant 2019, Samhouri *et al.* 2021). Along the west coast of the USA, state and federal agencies are collaborating to protect whales and reduce risks, with the goal of facilitating the recovery of whale populations. In waters off California, the two main threats are entanglement in trap-fishing gear nearshore (Rockwood *et al.* 2017, Feist *et al.* 2021) and ship strikes offshore. The ship strikes are inferred to be most common in the vicinity of large ports (Abrahms *et al.* 2019, Rockwood *et al.* 2020, Ingman *et al.* 2021, Rockwood *et al.* 2021, Saez *et al.* 2021; Fig. 1). Humpback Whales *Megaptera novaeangliae* (hereafter, humpbacks) have critical summer foraging habitat in the California Current system, where they are exposed to both these threats, especially as their populations increase (Curtis *et al.* 2022). Humpbacks shift their foraging habitats based on prey distribution; shifts in distribution to inshore waters can cause overlap with trap-fishing activities (Santora *et al.* 2020, Samhouri *et al.* 2021). Oceanographic indicators of upwelling conditions, which can affect prey distribution, have been developed to predict the risk of interactions between fisheries and whales in central California, but additional indicators have been requested by resource managers (Santora *et al.* 2020). There is a dynamic ocean management tool called WhaleSafe that incorporates modeled Blue Whale *Balaenoptera musculus* locations (Abrahms *et al.* 2019), visual sightings of cetaceans, and vocalizations from an underwater acoustic monitoring system for humpback, blue, and fin whales (Baumgartner *et al.* 2019). Recently, it has been used to encourage vessel compliance with voluntary speed reductions, and to inform shipboard personnel and conservation managers of ship-strike risk in real-time. With recent years serving as some of the worst on record for ship strikes, additional tools could be useful for mitigating this risk. Here, we show how the Western Gull *Larus occidentalis* (hereafter, gulls), an easily observed and common seabird species known to forage in association with Humpback Whales (Cimino *et al.* 2022), could also serve as a potential indicator for mitigating ship-strike risk to whales.

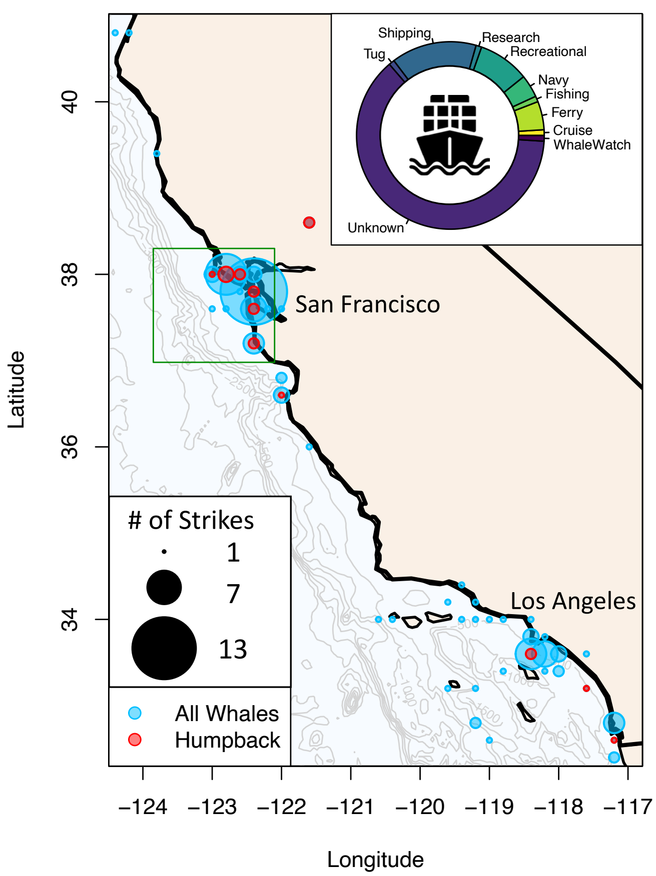

Fig. 1. The number of recorded ship strikes for all whales species (n = 102, including Humpback Whales *Megaptera novaeangliae*) and Humpback Whales only (n = 20) in California, USA, from 2007 to 2021. These totals are minimum numbers, as lacerations from strikes can be difficult to observe and whale carcass recover rates are low (< 1%–17%, NOAA National Marine Fisheries Service Stranding Database). Note, Humpback Whales are the focal whale species in this study, but all whale species are shown as a reference. Because the number of recorded ship strikes are low, the entire available record of whale ship strikes off California was shown to demonstrate regions where strikes are commonly observed. The pie chart shows the vessel types associated with all ship strikes. The green box is our study region (shown in Fig. 2), where 60% of reported Humpback Whale strikes occurred.

A combination of biologging and vessel location data can provide insight into where animals face threats from or interact with humans in marine environments (Votier *et al.* 2010, Weimerskirch *et al.* 2020, Giménez *et al.* 2021, Orben *et al.* 2021, Silva *et al.* 2022). In a previous study, we found that 70% of Western Gull at-sea distributions were associated with the presence of Humpback Whales (Cimino *et al.* 2022; Fig. A1 in the Appendix, available online). Gulls forage by surface seizing, contact dipping, and shallow plunge dives (Henkel 2009), and they often forage in association with whales, which drive prey to the surface. Thus, monitoring gull movement patterns might well offer a valuable indicator of whale presence (Veit & Harrison 2017, Cimino *et al.* 2022). Cimino *et al.* (2022) suggested that Western Gull movement patterns could provide fine-scale geographical information showing where whales may be at higher risk of ship strike or entanglements, but they did not test whether gulls encountered whales and vessels simultaneously—a critical link for establishing gulls as a good indicator, because they could actively avoid regions of high vessel traffic. Here, we build on these ecological findings by re-examining the interactions between GPS-tracked Western Gulls and vessel locations recorded using the Automatic Identification System (AIS; e.g., Kroodsma *et al.* 2018) to characterize gull encounters with vessels. We also evaluate whether gull behavior can serve as a proxy for whale presence, which can inform the models used to predict risk levels for the occurrence of ship strikes. Western Gulls are abundant in the San Francisco Bay region and breed at several offshore colonies, the largest of which is on Southeast Farallon Island (Ainley & Boekelheide 1990). This region of central California experiences a seasonally high density of Humpback Whales (Ingman *et al.* 2021), has a major port with high shipping and fishing vessel traffic, and is a known hotspot for ship strikes (Fig. 1).

Seabirds are attracted to vessels for many reasons: fishing boats discard fish offal, larger ships create wake eddies that stir up prey, and vessels of any type can be used for resting and/or roosting. Studies of Western Gull foraging ecology have shown that they respond rapidly to environmental variability. Having a wide diet consisting of dead or alive invertebrates and fish, they can also shift their foraging strategies to exploit landfills and urban centers when ocean prey are less abundant (Frechette *et al.* 2015, Osterback *et al.* 2015, Shaffer *et al.* 2017, Cimino *et al.* 2022). We hypothesize that when gulls are foraging at sea, they encounter a variety of vessel types, especially as several breeding colonies are located near busy shipping lanes; in particular, the Farallon Islands are at the outer terminus of the San Francisco Bay shipping channel. In this study, we aimed to determine the prevalence of gull-vessel encounters (i.e., instances where a gull contacts or interacts with a vessel), identify the types of vessels encountered, quantify the spatial and interannual variability of encounters, and identify potential drivers of encounters (e.g., vessel-associated foraging, transportation, incidental encounters, or vessel attraction). As Western Gulls from the Farallon Islands are known to feed in association with whales (Cimino *et al.* 2022), our secondary objective was to evaluate the distribution of gull-vessel encounters as a proxy for identifying areas where whales are at higher risk for ship strike. To do this, it is necessary to fully understand the number, location, and type of encounters between gulls and vessels.

METHODS

Western Gull data

From 2014 to 2019, Western Gulls were GPS-tracked during the incubation breeding phase at Southeast Farallon Island (37.697°N, 123.001°W), offshore of San Francisco Bay, California, USA (Shaffer *et al.* 2017; Table 1). Gull tracking at the Farallon Island National Wildlife Refuge was approved by the Institutional Animal Care and Use Committee at San José State University (protocol #979) and the US Fish and Wildlife Service Special Use Permits (SUP 81640 and 81641 to S.A. Shaffer). During incubation, gull pairs alternate duties at the nest: one parent forages while the other remains at the nest to incubate the eggs. Tracking procedures and data processing are described in Shaffer *et al.* (2017) and Cimino *et al.* (2022). Briefly, birds were captured twice using noose mats or a single-foot snare, once to deploy the GPS logger and again to recover it two to six days later. GPS data loggers (20-g igotU GT-120 or 32-g GT-600, Mobile Action Technology, Taiwan) recorded locations at one- to two-minute intervals (spatial accuracy: 3–4 m). A total of 120 adults were tracked (14 to 28 individuals each year) for roughly one to two weeks in late May to early or mid-June (Table 1). GPS tracks were linearly interpolated to a standardized two-minute interval (Table 1). The foraging trip metrics we calculated included trip duration and the location of stationary events or foraging events (i.e., travel speeds < 6 km·h^{-1} for ≥ 4 min; Shaffer *et al.* 2017), and we classified trips as trips solely at sea, trips that visited land, or trips within 5 km of the shoreline ("nearshore"; Cimino *et al.* 2022). These trip metrics were averaged annually to investigate interannual variability.

AIS and shipping lane data

We acquired AIS data from Global Fishing Watch from May and June 2014–2019 to match the biologging time-series of Western Gulls. AIS data were constrained within an area containing the greater San Francisco Bay region (36.6°N–38.4°N, 124°W–121°W; ~53 000 km^2 including land). AIS signals are broadcast at irregular intervals due to heterogeneous satellite coverage and device ping rate. In US waters, commercial vessels > 65 ft (19 m) are required to use class A AIS devices, as are some other categories of smaller vessels, such as certain types of tugboats and dredgers (USCG 2015). These regulations mean that although all large vessels are broadcasting AIS, this dataset likely does not include all medium and small commercial fishing or recreational vessels. We interpolated the AIS data to a regular two-minute interval to match the standardized gull tracks. AIS data within San Francisco Bay and Pillar Point Harbor (Half Moon Bay, ~40 km south of the Golden Gate Bridge) were removed because vessel density was high and because most vessels were anchored in the bays. This resulted in fly-by encounters when vessels were not underway, and thus, these encounters were not relevant to the aims of this study. Between 203 and 328 vessels were present within the region during the gull-tracking period each year (Table 1). AIS usage increased during our study period, as the 65-ft regulation for the US came into effect in March 2016.

Shipping lanes were downloaded from the National Oceanic and Atmospheric Administration's (NOAA) Office of Coast Survey electronic navigational charts. Vessels generally enter/exit the San Francisco Bay through one of three shipping lanes: the northern approaches (~60 km in length), the western approaches (~30 km), or the southern approaches (~40 km). Each has an inbound (north or west) and outbound (south or east) lane. The shipping lanes encompass a total area of 994 km^2 (Dransfield *et al.* 2014). The parallel inbound and outbound lanes for each approach are separated by a "separation zone". Use of these shipping lanes is voluntary, but they are regularly used for more efficient, organized, and safe navigation.

TABLE 1
Overview of the Western Gull tracking period, number of gulls tracked, number of foraging trips, and the total number of vessels in the gull foraging region during the tracking period for each year

Year	Tracking period (start)	Tracking period (end)	Number of gulls tracked[a]	Number of foraging trips	Number of vessels present during tracking period[b]	Humpback Whale relative abundance index[c]
2014	01 June	12 June	20	66	247	4.7
2015	24 May	03 June	14	51	238	13.4
2016	29 May	11 June	23	68	328	11.5
2017	28 May	04 June	14	39	203	1.3
2018	20 May	31 May	28	169	277	17.2
2019	20 May	31 May	21	139	277	12.9
Total			120	532	1570	

[a] Gull data are from Cimino *et al.* (2022).
[b] The number of vessels present should be considered a minimum, as not all vessels carry an AIS and AIS requirements changed during our study period.
[c] The index of relative abundance for Humpback Whales is the anomaly of visually sighted whales standardized by the encounter rate (described in Santora *et al.* 2020).

Identifying gull-vessel encounters

We defined at-sea encounters between gulls and vessels as events in which gulls and vessels were less than 0.1° apart in distance (*ca.* 1.1 km) and less than one minute apart in time. The "wildlifeDI" package (Long *et al.* 2014) and the "adehabitatLT" package in R version 0.4.0 (Calenge *et al.* 2009) were used to find encounters. Each gull track was converted into a trajectory object (i.e., location track) using the *as.ltraj* function, and AIS locations within the same space-time bounds were identified. The AIS locations associated with each gull track were grouped by vessel identification number (Maritime Mobile Service Identity, MMSI) and converted into trajectory objects. The *prox* function was used to find encounters between each gull and vessel track by finding the nearest single vessel location in time to each gull location. Because gull and vessel tracks were standardized to regular two-minute intervals, the nearest single vessel location in time to each gull location was on average 27 ± 15 s apart (maximum 59 s). Resultant encounters were filtered to exclude those greater than 0.01° apart. Within each unique match between gull and vessel tracks, encounters were considered separate events when more than 20 minutes elapsed between the end of one encounter and the start of another. For each gull-vessel encounter, we manually looked up the vessel type from MarineTraffic.com using each vessel's MMSI. We calculated the total number and proportion of vessels and encounters for each vessel type. We grouped vessels into five categories: cargo ships (oil/gas tanker, bulk carrier, container ship, and vessel carrier), fishing vessels, pleasure craft, tug and pilot boats, and other vessels (research vessel, dredger, high-speed craft, unknown).

Next, we determined the nature of gull-vessel encounters to understand whether gulls could be used to mitigate negative vessel impacts on whales. We grouped encounters into three types: 1) foraging-associated encounters, where encounters included a foraging event; 2) transportation encounters, where the gull was riding aboard the vessel; and 3) incidental encounters or vessel attractions, which occurred when a vessel and gull crossed paths either incidentally or when the gull changed its flight path to presumably view the vessel. For foraging encounters, we determined whether the gull was foraging before or after the encounter began. To identify if a gull was riding on a vessel, we calculated the bearing and speed for both gull and vessel tracks. Then, we calculated the difference in bearing and speed for each unique gull-vessel encounter, along with the average difference in bearing and speed across the full encounter. A gull was considered to be riding on a vessel if the average difference in bearing was less than 0.6° and the average difference in speed was < 1.1 m/s. This information was summarized by year. Comparing these three types of encounters allowed for a quantification of how prevalent each encounter type was in relation to the others, which is important for understanding the utility of using gulls as an indicator of ship-strike risk. The mean and standard deviation in encounter duration was also determined to compare different encounter types.

Whale data

Ship-strike information was acquired from the NOAA Fisheries National Stranding Database. This database contains data from stranding report forms, which are completed every time a member of the stranding network responds to a stranded mammal in the US.

Information such as date, location, species, and vessel type were available from 2007 to 2021. The vessel type and the exact location of the strike was often unknown but, when possible, locations were inferred from carcass observations. These data were summarized to show overall spatial patterns and the diversity of vessel types involved in ship strikes off California. A total of 102 ship strikes were reported during 2007–2021, and 20 of these were identified as involving a humpback. For 10% of strikes, the species was unknown. Because ship-strike reports are spatially coarse, we visualized the entire record to show locations where strikes have occurred more frequently.

We used a Humpback Whale Relative Abundance Index as an indicator of prey availability for foraging gulls, because whales are known to drive prey toward the surface and gulls, at best, are capable of only shallow plunge dives (to a depth of 1 m). It is likely that gulls associate with other foraging whale species at sea, but we have no data for species other than humpbacks. Visual observations of humpbacks were recorded during the annual Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) conducted by NOAA's National Marine Fisheries Service (NOAA-NMFS) in waters over the continental shelf in late April through mid-June. Visual surveys occurred continuously during daylight hours. The sampling unit was the number of whales sighted per 3-km interval, and the anomaly was the abundance index standardized by the encounter rate (i.e., number of whales per 100 km of survey effort; described in Santora *et al.* 2020). This Humpback Whale Relative Abundance Index was downloaded from the NOAA's California Current Integrated Ecosystem Assessment. Overlap between foraging gulls and humpback distribution was described in Cimino *et al.* (2022).

Analysis

Gull biologging and AIS data was summarized annually from 2014 to 2019. We calculated the total number of encounters each year by vessel category, along with the proportion of tracked gulls that encountered vessels each year (response variable). We tested models to determine if gull-vessel encounters each year were related to: 1) relative Humpback Whale abundance (i.e., prey availability); 2) gull foraging behavior (i.e., the proportion of foraging events that occurred on land and nearshore, and the mean duration of foraging trips that were solely at sea); and 3) sample-size effects related to both the total number of vessels within the gull foraging region during the tracking period and the total number of gull foraging trips (Table 1).

We followed the approach of Cimino *et al.* (2022), which tested whether the proportion of gull foraging events nearshore and on land were related to ocean conditions and prey abundances each year. As this previous analysis revealed relationships between foraging on land/nearshore with ocean and prey conditions, our models here focused on drivers of the proportion of tracked gulls that encountered vessels with the three categories of independent variables described above that complement previous work. Briefly, we used generalized additive models fit using the "mgcv" package (R Core Team 2020) with the "betar" family and tested for non-linear relationships using a smoothness parameter estimated by generalized cross-validation. When non-linear relationships were not present, we omitted the smoothness parameter. We tested six bivariate models, which included only one term due to a low sample size. We used the Akaike Information Criterion corrected for small sample size (AIC_c) to rank model performance; models with a delta AIC_c < 2 were considered to have substantial support and those

> 10 had no support (Burnham & Anderson 2002). We report the R^2, deviance explained, and Akaike weight for each model.

Data availability statement

The data underlying this article are available from Global Fishing Watch (https://globalfishingwatch.org/map-and-data/), the Animal Telemetry Network (https://portal.atn.ioos.us/#metadata/20adbe37-d59b-4bf6-a2e0-db725ecbd29c/project), the NOAA Fisheries National Stranding Database (https://www.fisheries.noaa.gov/national/marine-life-distress/national-stranding-database-public-access), and the NOAA Integrated Ecosystem Assessment (https://oceanview.pfeg.noaa.gov/cciea-table/?opentab=1&report=whale_entanglement).

RESULTS

Spatial patterns and description of gull-vessel encounters

We visualized hotspots of whale ship strike along the California coast, which showed strikes were most prevalent near the ports of San Francisco and Los Angeles (Fig. 1). While 63% of vessels responsible for the strikes were unknown, the remaining vessel types were diverse, with cargo vessels accounting for 15% of strikes. The gull at-sea foraging region in this study contained nearly all shipping lanes leading to/from the Golden Gate, roughly from Año Nuevo to Point Reyes and from the coast to the shelf break (Fig. 2A).

Gull-vessel encounters occurred mainly within (79%) or adjacent to the shipping lanes, especially in lanes or areas of the lanes that were nearest the gull breeding colony (Fig. 2A). Gulls often made repeated and direct foraging trips from their colony to coastal areas where they foraged along the shoreline or at landfills, following a linear trajectory from the colony to shore that required briefly crossing the shipping lanes. The types of vessels that gulls encountered were diverse (Fig. 2). Encounters with tug/pilot boats and cargo ships were nearly all located within the shipping lanes, whereas encounters with fishing vessels, pleasure craft, and other vessels were more dispersed and generally outside of the shipping lanes (Fig. 2A).

There were gull-vessels encounters recorded in each year of the study (Table 1). A total of 48 birds (40% of tracked birds) interacted with 49 vessels (3% of all AIS-transmitting vessels present in the gull foraging range during the tracking periods). Of these 49 vessels, most were in the cargo ship category (Fig. 2B). There was a total of 85 encounters, and 77 of these were unique (i.e., different vessel and gull), meaning that some gulls interacted with the same vessel twice (Fig. 2C). Of the 85 encounters, most were with tug/pilot boats, cargo ships, and pleasure craft (Fig. 2C), and 11 vessels encountered more

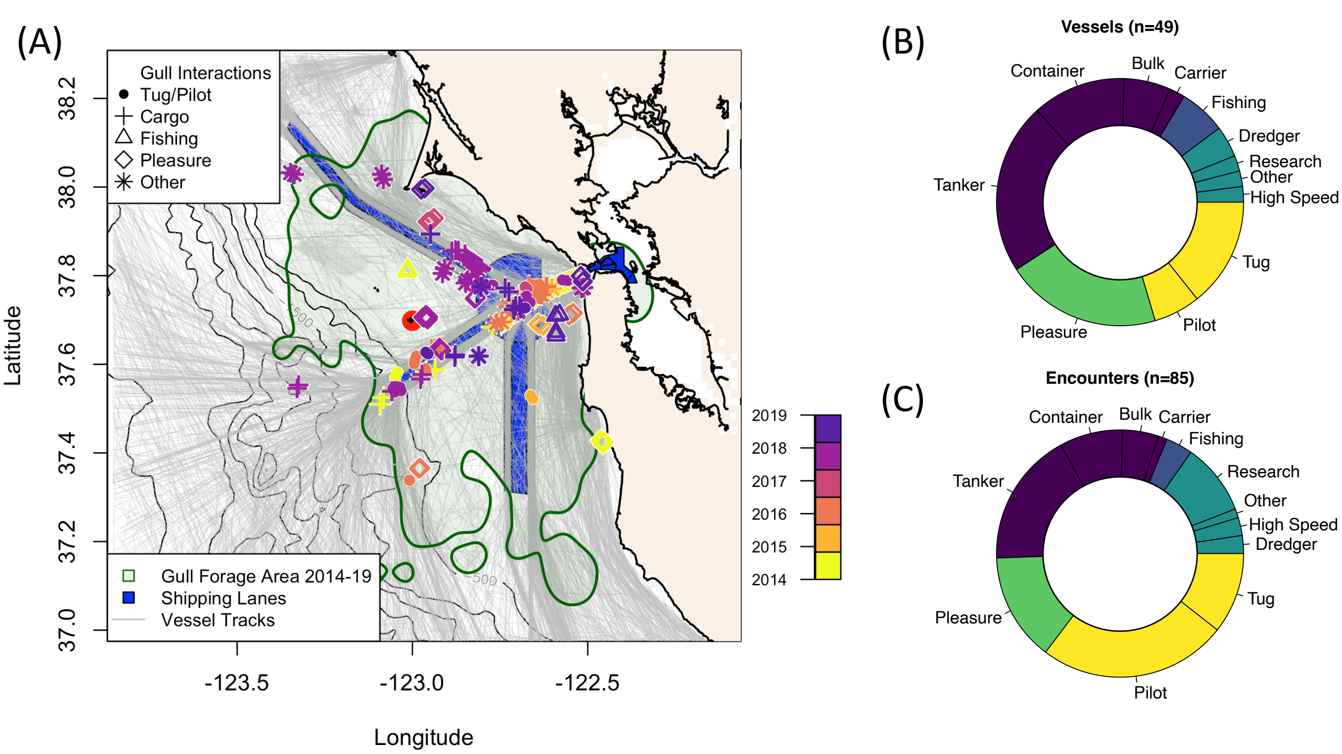

Fig. 2. The Western Gull *Larus occidentalis* at-sea foraging region in relation to vessel tracks, vessel interactions and the shipping lanes associated with entry-exit of San Francisco Bay (in California, USA) through the Golden Gate. A) Colored points represent encounters between an individual vessel and gull for each year where the symbol represents the vessel type. The gull foraging region is the 95% kernel density estimate for all years in this study. The vessel tracks shown are only those within the gull-tracking periods (Table 1). The red circle is Southeast Farallon Island – the location of the gull breeding colony. B) Gulls encountered 49 different vessels with the pie chart showing the proportion of vessels by type. The color represents the general vessel categories shown on the right (e.g., dark blue are cargo ships and lighter blue are other vessel types). c) As multiple birds encountered the same vessels (or vice versa), the total number of encounters was 85 with the pie chart showing the proportion of encounters by vessel type.

than one gull. For example, one pilot ship (P/V *San Francisco*) encountered eight different tracked gulls and the NOAA fisheries science vessel (FSV) *Reuben Lasker* encountered seven gulls. Of the 48 gulls, 18 interacted with more than one vessel. For example, one gull (#201822001) interacted with four different vessels during two trips and another gull (#201622008) interacted with five different vessels during three trips. Overall, the gull-vessel encounters took place during 62 different gull foraging trips; thus, there were a few cases where a gull encountered more than one vessel on a single trip.

Gulls interacted with vessels in different ways. Some encounters seemed incidental (e.g., crossing paths or interruption of foraging), while others appeared intentional (e.g., gulls riding on vessels or changing course toward a vessel; Fig. 3). Of the 85 encounters, 32% (n = 27) were associated with a foraging event, and for 41% of these encounters (11 of the 27), the foraging event started after the encounter started. This suggests that a gull's decision to stop may have been influenced by the close association with the vessel. In these cases, the vessel types involved were cargo ships (n = 3), fishing vessels (n = 1), tug/pilot boats (n = 4), pleasure craft (n = 1) and other vessels (n = 2); 82% (9 of 11) were within the shipping lanes. These encounters lasted on average 20.7 ± 32.4 minutes. Conversely, for the other 60% of foraging-associated encounters (16 of 27), the vessel may have interrupted foraging behavior that started before the encounter began. In these cases, the vessel types involved were cargo ships (n = 7), tug/pilot boats (n = 3), pleasure craft (n = 3) and other vessels (n = 3); 75% (12 of 16) were within the shipping lanes. These encounters lasted on average 9.4 ± 16.9 minutes. In addition, there were four gull-vessel encounters by three different individuals where the gull rode on the vessel (5% of all encounters). Three of these vessels were cargo ships and one was a tug/pilot boat, and these events occurred on the gull's transit to/from their colony within the shipping lanes. The encounters lasted 33.0 ± 27.4 minutes. All other encounters averaged 2.9 ± 2.8 minutes.

Interannual variability in gull-vessel encounters

The number of encounters between gulls and vessels varied by year, ranging from 2 to 26 encounters (Fig. 4A). The most encounters occurred in 2016 and 2018 (~25) and the fewest in 2015 and 2017 (≤ 5). This followed a similar pattern in the number of individuals tracked and foraging trips: we tracked roughly 25 individuals in 2016 and 2018 (68 and 169 trips), and 14 individuals in 2015 and 2017 (51 and 39 trips; Table 1). The lowest number of vessels present in the gull foraging region during the tracking period was in 2017 (n = 203; Table 1). Further, the Humpback Whale Relative Abundance Index followed a pattern similar to both encounters and number of vessels, with the lowest abundance in 2017 and highest in 2018 (Table 1). There were encounters with pleasure craft and tug/pilot boats each year. There were 15 encounters with tug/pilot boats in 2016, and nine encounters with cargo vessels in 2018 (Fig. 4A).

About 30%–50% of the tracked gulls encountered a vessel each year (Fig. 4B), except for 2017 when only 14% did so. In general, > 50% of the encounters each year were either incidental or facilitated by vessel attraction (Fig. 4C). The rare cases where a gull rode on a vessel occurred in 2014 (n = 3) and 2018 (n = 1). For foraging-associated encounters, foraging generally started before the vessel encounter began (mean = 18% of encounters each year, range = 7%–27%) compared to after the encounter (mea$n$ = 13%, range = 7%–20%), except for 2017 when there were no foraging-associated encounters (Fig. 4C).

Drivers of gull-vessel encounters

We tested whether whale abundance, gull foraging behavior, the number of vessels, and the number of gull foraging trips were related to the proportion of tracked gulls that encountered a vessel each year from 2014 to 2019 (Table 2, Fig. A2). The two most-supported models ($\Delta AIC_c < 2$) included the proportion of foraging events nearshore and on land, explaining 75% of the deviance. The proportion of foraging events on land and nearshore were positively correlated to each other (R = 0.70, p = 0.12). There were more gull-vessel encounters when the proportion of foraging nearshore ($z = -3.30$, $p = 0.001$) and on land ($z = -3.00$, $p = 0.003$) were low; in other words, there were more encounters when gulls foraged at sea. Other less-supported models (ΔAIC_c = 3.0–4.8) also explained a large portion of the deviance (40%–60%) and revealed there were more gull-vessel encounters when samples were large (vessels: $z = 1.70$, $p = 0.08$; trips: $z = 2.30$, $p = 0.02$), durations of trips at sea were short ($z = -1.90$, $p = 0.05$), and whale abundance was high ($z = 1.70$, $p = 0.09$).

DISCUSSION

Our analysis of Western Gull movements and vessel encounters improves our understanding of the patterns and drivers of bird-vessel associations near the busy port of San Francisco and provides insight into mitigating whale ship strike. Gulls interacted with vessels in different ways, and the interannual variability of encounters was predominantly related to where gull foraging was concentrated. Vessel traffic is highest in the shipping lanes, which was where most gull-vessel encounters occurred. This is also presumably where most whale ship strikes would occur, but specific details are often unknown. Acquiring frequent and accurate information on Humpback Whale distributions is challenging, as whales are mobile; sea/aerial surveys are both costly and plagued by bad weather. Therefore, the previously reported foraging associations between gulls and humpbacks (i.e., Cimino *et al.* 2022), coupled with the encounters between vessels and foraging gulls shown here, provides support for processing seabird biologging data in real-time and using gull foraging behavior as another potential indicator for evaluating the risk levels to whales.

Patterns in the types of gull-vessel encounters

Western Gulls interacted with a variety of vessel types in different ways. Overall, most gull-vessel encounters were short, either incidental or related to vessel attraction; it is unclear if or how much disturbance these encounters cause. Gulls mainly encountered vessels within the shipping lanes, and there were relatively few observed encounters with fishing vessels. Our results undoubtedly undercount gull encounters with fishing vessels because most commercial fishing vessels (85%) are smaller than 65 ft and thus not required to participate in AIS (USCG 2017). Fishing vessels offer foraging opportunities for seabirds (Oro *et al.* 2013, Patrick *et al.* 2015, Sherley *et al.* 2020), where birds may seek out fishing vessels and adapt their foraging strategies to exploit fisheries resources (Votier *et al.* 2010, Patrick *et al.* 2015, Weimerskirch *et al.* 2018, Corbeau *et al.* 2019). A targeted analysis using vessel locations from the Vessel Monitoring System (VMS), a mandatory

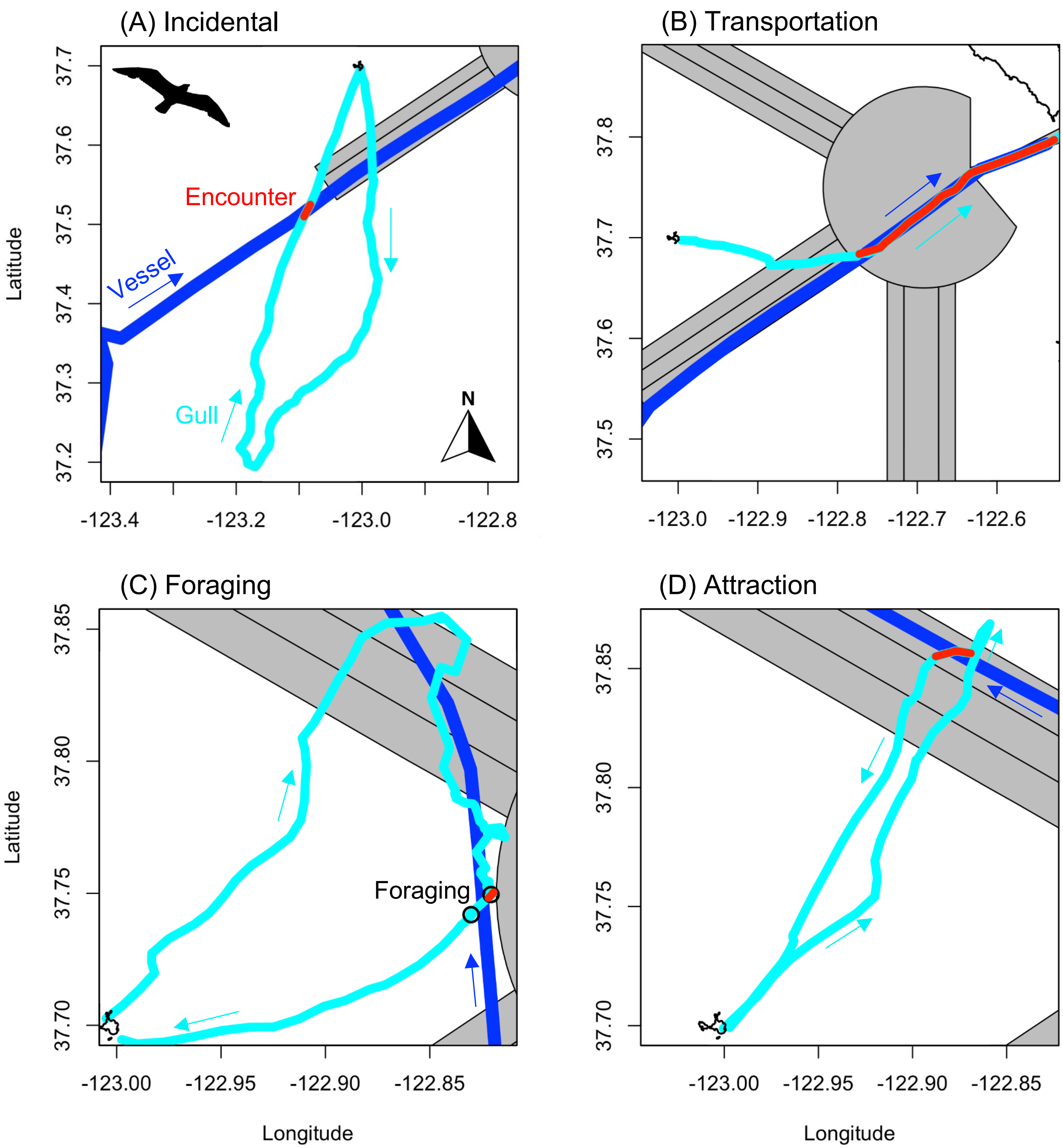

Fig. 3. Examples of Western Gull *Larus occidentalis* encounters with vessels off California, USA. A) An incidental encounter (red) where a vessel (blue) and gull (cyan) cross paths with no apparent change in the gull's flight path. B) An example of a gull riding on a vessel. C) Gull foraging events (black circles) interrupted by a vessel encounter. D) A gull changes course (180°) and briefly flies over a passing vessel. Shipping lanes are in gray, and arrows denote direction of travel. All gull tracks start at Southeast Farallon Island.

program for US-flagged commercial fishing vessels, is needed to fully understand fishery associations with foraging gulls (e.g., Votier *et al.* 2010, Giménez *et al.* 2021).

Encounters in which a vessel interrupted a gull's foraging behavior (20% of encounters) are not insignificant. Although gulls are highly mobile and can quickly fly away to avoid an oncoming ship, a feeding whale may not be able to respond as quickly and, thus, may be at greater risk of strike. Further, the presumed flushing of gulls while foraging could be a disturbance that reduces their foraging efficiency, increases energetic costs, or results in a loss of suitable habitat that could have cascading effects on reproductive success

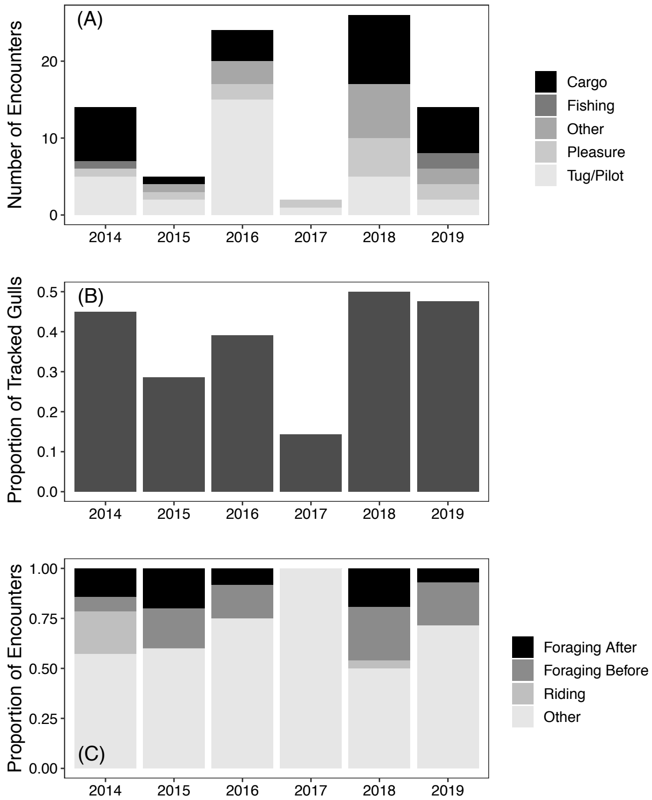

Fig. 4. Interannual variability in Western Gull *Larus occidentalis* encounters with vessels from 2014 to 2019. A) The number of encounters by vessel types each year. B) The proportion of tracked gulls that had a vessel encounter each year (the response variable in the generalized additive models). C) For each year, the proportion of encounters that were associated with gull foraging events, transportation by gulls riding aboard vessels, or other (i.e., incidental or vessel attraction). For the proportion of encounters associated with gull foraging events, we determined if the foraging event began before or after the vessel encounter.

(Korschgen *et al.* 1985, Bamford *et al.* 1990, Carney & Sydeman 1999, Schummer & Eddleman 2003).

One of the more intriguing observations was the use of vessels by gulls, particularly large cargo ships, for transportation to their colony from coastal areas (or vice versa). These encounters were generally longer in duration (~30 minutes) than other encounter types, and one individual gull rode on a ship twice, suggesting intentionality of this behavior. Although this behavior is not widely documented in the literature, there are accounts of ship-assisted arrivals to new regions (e.g., Gonzales 2006 and references within, Jamalabad 2016) and migrating birds using ships as stopovers during adverse weather (Sarà *et al.* 2023). The House Crow *Corvus splendens* and Peregrine Falcon *Falco peregrinus* are a few of the land birds known to deliberately hitch rides on ships; the former use ships to facilitate their dispersal (Cheke 2008) and the latter use them as a foraging strategy to target migrant land birds (D. Ainley pers. comm.). Gulls were also observed to land on the FSV *Reuben Lasker* (Santora pers. obs.), which had many encounters with tracked gulls in our study.

Interannual variability and drivers of gull-vessel encounters

There was interannual variability in the number of encounters, the vessel types that were encountered, and the gull behaviors associated with each encounter. Interannual variability in the proportion of tracked gulls that encountered a vessel was mostly related to where gulls were foraging. Western Gulls are known to forage both at sea and on land (Frechette *et al.* 2015, Shaffer *et al.* 2017), and the choice of foraging location is most likely associated with interannual variations in oceanic resources and individual preferences (Spear 1988). For example, previous research showed that gulls foraged nearshore and on land when prey abundances and relative Humpback Whale abundances were low (Cimino *et al.* 2022). During 2017 in particular, most gulls foraged on land, at-sea foraging conditions were poor, whale abundances were lowest (Wells *et al.* 2017, Thompson *et al.* 2019), and the number of gull-vessel encounters was lowest. Hence, this could be considered a

TABLE 2
Generalized additive models relating the proportion of tracked gulls that encountered a vessel each year to Humpback Whale relative abundance, gull foraging behavior (i.e., proportion of foraging trips nearshore or on land, sea trip duration), and sample sizes (i.e., total number of foraging trips and total number of vessels)

Model	R^2	Deviance Explained	AIC_c[a]	ΔAIC_c[b]	Akaike Weight[c]
Proportion of tracked gulls that encountered a vessel (n = 6) ~					
Proportion nearshore foraging	0.68	75.0	2.7	0.0	0.43
Proportion land foraging	0.61	72.9	3.2	0.5	0.34
Total trips	0.48	58.3	5.7	3.0	0.10
Sea trip duration	0.42	47.2	7.0	4.3	0.05
Total vessels	0.24	45.9	7.2	4.5	0.04
Humpback abundance	0.22	43.1	7.5	4.8	0.04

[a] Akaike information criterion for small sample size (AIC_c).
[b] ΔAIC_c indicates the amount of information lost using AIC_c and is the difference from the lowest AIC_c value.
[c] Akaike weight indicates model support.

period of low ship-strike risk for whales (Fig. A1). We found gulls encountered more vessels when more foraging occurred at sea and when trip durations were short, potentially because short trips had greater overlap with the nearby shipping lanes. We also found, as expected, that there were more gull-vessel encounters as sample sizes increased.

Implications for management

Vessels pose a risk to seabird and marine mammal populations globally in a multitude of ways, including collision, pollution, habitat alteration, acoustic disturbance, and visual disturbance. For seabirds, these encounters can cascade from parental to offspring impacts (Carney and Sydeman 1999). The long-term presence of vessels in the vicinity of the Farallon Islands may suggest a high level of habituation that make local birds less susceptible to human disturbance (Fliessbach *et al.* 2019); associating with fishing vessels could benefit them in terms of food acquisition. Further study is needed to determine if population-level consequences (positive or negative) from ship disturbance exist for Western Gulls, given that we lack information on smaller (< 65 ft) fishing vessels and whether vessels were eliciting behavioral responses (e.g., interrupting foraging behavior, providing a platform for transportation, altering flying behavior through visual attraction).

Vessel collision is a primary cause of whale injury and death, and it is an inhibitor of whale recovery (Barcenas-De la Cruz *et al.* 2018). Humpback Whales migrate through coastal central California in the late spring to fall (Ingman *et al.* 2021), which overlaps with the breeding period for Western Gulls at the Farallon Islands. Ship-strike exposure and risk are highest near large ports with high volumes of vessel traffic during summer months when whales are present, with the Gulf of Farallones area accounting for a high percentage of humpback strike mortality off California (Fig. 1; Rockwood *et al.* 2017, Keen *et al.* 2019, Rockwood *et al.* 2020). Hence, this should be one of the priority regions for ship-strike mitigation; additional tools that can provide high-resolution information on probable locations of whales should also be developed. The feeding associations between gulls and whales (Cimino *et al.* 2022) indicate that foraging gulls could be an indicator of areas of higher humpback ship-strike risk, especially because whales can be difficult to visually observe and avoid from large vessels (Cope *et al.* 2020). Further, tracking seabirds is cost-effective and less labor intensive than standard methods used to monitor whale distributions.

Data dissemination through data dashboards or dynamic ocean management tools can provide information at the most appropriate scales for marine resource management. In central California, there are several existing data dashboards (e.g., California Current Integrated Ecosystem Assessment Indicators) and mapping tools (e.g., WhaleSafe) that show annual, seasonal, or real-time data with predictions of species distribution and abundance. Dynamic ocean management tools provide effective ways to merge disparate datasets and reduce threats to species that vary in space and time (Lewison *et al.* 2015, Maxwell *et al.* 2015). To make the most informed management decisions, dynamic ocean management tools should strive to integrate as much information as possible to understand the state of the ecosystem, especially as recent years show anomalous and unexpected species occurrence patterns that rival our understanding of species-habitat associations. While our tracking study on Western Gulls was short (i.e., 1–2 weeks each year) and occurred before peak whale abundances, we posit that gull locations could provide important information on whale distributions if a proportion of the population (approx. 30 individuals) were equipped with year-round devices that transmit near real-time GPS data.

Within existing management tools, gull foraging data could offer real-time maps of foraging behavior and habitat to identify overlaps with shipping lanes and existing whale distribution data (e.g., whale models, sightings, vocalizations). Gull-tracking data indicated that foraging ranges did not overlap all three shipping lane approaches across multiple years (see Cimino *et al.* 2022). Thus, gull-tracking information could be useful for identifying which shipping lanes might have the greatest whale ship-strike risk each year (Fig. A1). Foraging locations derived from the tracks can also provide insight on the proportion of foraging occurring on land, an indicator of low whale abundance, and thus, provide an indication of lower ship-strike risk (Fig. A1). The automated processing of gull-tracking data could be directly integrated and visualized in existing ocean observing tools.

Current whale indicators and proposed gull indicators here provide different yet complementary information on various scales. For example, gull GPS tracks provide high-resolution (minutes, meters) information compared to some of the other whale indicators, where visual observations are patchy (i.e., restricted to daytime and good weather, available at irregular intervals), model predictions are of coarser resolution (daily, ~1–10 km), acoustic vocalization data can have high temporal resolution but high spatial uncertainty (~40 km; Baumgartner *et al.* 2019), and identified oceanographic indicators are available in 1° bins along the coast (Santora *et al.* 2020). Therefore, merging higher-resolution gull information with established whale proxies could be useful in further understanding times and locations where whales are at risk.

When there are high rates of gull foraging and other indicators show whales are present, ship-strike mitigation strategies could include vessel route adjustments (e.g., temporary shipping lane closures, designation of regions to be avoided) and/or speed restrictions (e.g., reductions in potential ship-strike risk zones); much work has been done to show these strategies are proven to reduce risk (Laist *et al.* 2014, Cope *et al.* 2020, Rockwood *et al.* 2020, Rockwood *et al.* 2021). As discussed above, integrated management approaches that combine many data types could provide information on probable ecological hotspots and more comprehensive management tools to protect whales (a view also supported by Silva *et al.* 2022).

To further understand seabird-cetacean relationships, we advocate for an exploration of VMS data to further understand bird interactions with fishing vessels. Additionally, studies that track both whales and gulls simultaneously in the same region could provide a more detailed account of their fine-scale ecological relationship. There are also other species of nesting seabirds that likely interact with vessels and/or marine mammals. For example, in the Atlantic, Great Shearwaters *Ardenna gravis* co-occur with Humpback Whales, confirming the use of other species to monitor whale locations (Silva *et al.* 2022). There are about 50 species of gulls *Larus* spp. that occupy coastal zones around the globe and form multi-species feeding associations, and they could also serve as informative indicators of environmental conditions or locations where cetaceans face risks from human activities. Therefore, employing the approach used here for other species or in different locations could further aid in elucidating bird-mammal-vessel interactions, possible disturbances to birds or other species they associate with, and possible foraging benefits for birds that associate with fishing vessels. Together, this information can be used to mitigate human impacts on ecologically important and protected species, given the rise in commercial shipping traffic globally.

ACKNOWLEDGEMENTS

Our research was supported by grants from San José State University's Research, Scholarship, and Creative Activity program (SJSU-RSCA); California State University's Council on Ocean Affairs, Science & Technology (CSU COAST); and the Earl H. and Ethel M. Myers Oceanographic and Marine Biology Trust. We thank students and Point Blue Conservation Science staff on the Farallon Islands for assisting with gull field research. We thank the US Fish and Wildlife Service for granting permission and providing resources for research on the Farallon Islands National Wildlife Refuge, as well as the captains and crews of the Farallon Patrol, including the Army Corps of Engineers. Funding was also provided by the National Aeronautics and Space Administration (NASA) and the US Marine Biodiversity Observation Network (MBON; 80NSSC20M0001). We thank the NOAA-NMFS RREAS team and the Farallon Institute for maintaining visual surveys. We thank Stephanie Brodie and reviewers for comments, the addressing of which have improved the manuscript.

REFERENCES

ABRAHMS, B., WELCH, H., BRODIE, S., ET AL. 2019. Dynamic ensemble models to predict distributions and anthropogenic risk exposure for highly mobile species. *Diversity and Distributions* 25: 1182–1193. doi:10.1111/ddi.12940

AINLEY, D.G. & BOEKELHEIDE, R.J. (Eds.) 1990. *Seabirds of the Farallon Islands: Ecology, Dynamics, and Structure of an Upwelling-System Community.* Stanford, California: Stanford University Press.

BAMFORD, A.R., DAVIES, S.J.J.F. & VAN DELFT, R. 1990. The effects of model power boats on waterbirds at Herdsman Lake, Perth, Western Australia. *Emu* 90: 260–265. doi:10.1016/0006-3207(92)90639-5

BARCENAS-DE LA CRUZ, D., DERANGO, E., JOHNSON, S.P. & SIMEONE, C.A. 2018. Evidence of anthropogenic trauma in marine mammals stranded along the central California coast, 2003–2015. *Marine Mammal Science* 34: 330–346. doi:10.1111/mms.12457

BAUMGARTNER, M., BONNELL, J., VAN PARIJS, S.M., ET AL. 2019. Persistent near real-time passive acoustic monitoring for baleen whales from a moored buoy: System description and evaluation. *Methods in Ecology and Evolution* 10: 1476–1489. doi:10.1111/2041-210X.13244

BURNHAM, K.P. & ANDERSON, D.R. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach.* New York, USA: Springer.

CALENGE, C., DRAY, S. & ROYER-CARENZI, M. 2009. The concept of animals' trajectories from a data analysis perspective. *Ecological Informatics* 4: 34–41. doi:10.1016/j.ecoinf.2008.10.002

CARNEY, K.M. & SYDEMAN, W.J. 1999. A review of human disturbance effects on nesting colonial waterbirds. *Waterbirds* 22: 68–79. doi:10.2307/1521995

CARRETTA, J.V., MUTO, M.M., WILKIN, S., ET AL. 2015. *Sources of Human-Related Injury and Mortality for US Pacific West Coast Marine Mammal Stock Assessments, 2009–2013.* NOAA Technical Memorandum NMFS-SWFSC-548. Washington, USA: National Oceanic and Atmospheric Administration.

CHEKE, A. 2008. Seafaring behaviour in House Crows *Corvus splendens* – a precursor to ship-assisted dispersal? *Phelsuma* 16: 65–68.

CIMINO, M.A., SHAFFER, S.A, WELCH, H., ET AL. 2022. Western Gull foraging behavior as an ecosystem state indicator in coastal California. *Frontiers in Marine Science* 8: 790559. doi:10.3389/fmars.2021.790559

COPE, S., HINES, E., BLAND, R., DAVIS, J.D., TOUGHER, B. & ZETTERLIND, V. 2020. Application of a new shore-based vessel traffic monitoring system within San Francisco Bay. *Frontiers in Marine Science* 7: 86. doi:10.3389/fmars.2020.00086

CORBEAU, A., COLLET, J., FONTENILLE, M. & WEIMERSKIRCH, H. 2019. How do seabirds modify their search behaviour when encountering fishing boats? *PLoS One* 14: e0222615. doi:10.1371/journal.pone.0222615

CURTIS, K.A., CALAMBOKIDIS, J., AUDLEY, K., ET AL. 2022. *Abundance of Humpback Whales* (Megaptera novaeangliae) *Wintering in Central America and Southern Mexico from a One-Dimensional Spatial Capture-Recapture Model*. NOAA Technical Memorandum NMFS-SWFSC-661. Washington, USA: National Oceanic and Atmospheric Administration. doi:10.25923/9cq1-rx80

DAVIES, K.T.A. & BRILLANT, S.W. 2019. Mass human-caused mortality spurs federal action to protect endangered North Atlantic Right Whales in Canada. *Marine Policy* 104: 157–162. doi:10.1016/j.marpol.2019.02.019

DRANSFIELD, A., HINES, E., MCGOWAN, J., ET AL. 2014. Where the whales are: Using habitat modeling to support changes in shipping regulations within National Marine Sanctuaries in Central California. *Endangered Species Research* 26: 39–57. doi:10.3354/esr00627

FEIST, B.E., SAMHOURI, J.F., FORNEY, K.A. & SAEZ, L.E. 2021. Footprints of fixed-gear fisheries in relation to rising whale entanglements on the US West Coast. *Fisheries Management and Ecology* 28: 283–294. doi:10.1111/fme.12478

FLIESSBACH, K.L., BORKENHAGEN, K., GUSE, N., MARKONES, N., SCHWEMMER, P. & GARTHE, S. 2019. A ship traffic disturbance vulnerability index for Northwest European seabirds as a tool for marine spatial planning. *Frontiers in Marine Science* 6: 192. doi:10.3389/fmars.2019.00192

FRECHETTE, D., OSTERBACK, A.-M.K., HAYES, S.A., ET AL. 2015. Assessing the relationship between gulls *Larus* spp. and Pacific Salmon in central California using radiotelemetry. *North American Journal of Fisheries Management* 35: 775–788. doi:10.1080/02755947.2015.1032450

GIMÉNEZ, J., ARNEILL, G.E., BENNISON, A., ET AL. 2021. Sexual mismatch between vessel-associated foraging and discard consumption in a marine top predator. *Frontiers in Marine Science* 8: 636468. doi:10.3389/fmars.2021.636468

GONZALES, J.C. 2006. Impact of introduced birds in the Philippines. *Journal of Environmental Science and Management* 9: 66–79.

GRÉMILLET, D., PONCHON, A., PALECZNY, M., PALOMARES, M.-L.D., KARPOUZI, V. & PAULY, D. 2018. Persisting worldwide seabird-fishery competition despite seabird community decline. *Current Biology* 28: 4009–4013. doi:10.1016/j.cub.2018.10.051

HAZEN, E.L., ABRAHMS, B., BRODIE, S., ET AL. 2019. Marine top predators as climate and ecosystem sentinels. *Frontiers in Ecology and the Environment* 17: 565–574. doi:10.1002/fee.2125

HENKEL, L.A. 2009. Co-occurrence and aggregation of marine birds and mammals in Monterey Bay, California, USA. *Marine Ecology Progress Series* 387: 295–303. doi:10.3354/meps08082

INGMAN, K., HINES, E., MAZZINI, P.L.F., ROCKWOOD, R.C., NUR, N. & JAHNCKE, J. 2021. Modeling changes in baleen whale seasonal abundance, timing of migration, and environmental variables to explain the sudden rise in entanglements in California. *PLoS One* 16: e0248557. doi:10.1371/journal.pone.0248557

JACKSON, J.B.C., KIRBY, M.X., BERGER, W.H., ET AL. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293: 629–637. doi:10.1126/science.1059199

JAMALABAD, A. 2016. Records of a White-eyed Gull *Ichthyaetus leucophthalmus*, and a Black Tern *Chlidonias niger* from the Karwar coast, Karnataka, India. *Indian Birds* 12: 12–14.

KEEN, E.M., SCALES, K.L., RONE, B.K., HAZEN, E.L., FALCONE, E.A. & SCHORR, G.S. 2019. Night and day: Diel differences in ship strike risk for Fin Whales (*Balaenoptera physalus*) in the California current system. *Frontiers in Marine Science* 6: 730. doi:10.3389/fmars.2019.00730

KORSCHGEN, C.E., GEORGE, L.S. & GREEN, W.L. 1985. Disturbance of diving ducks by boaters on a migrational staging area. *Wildlife Society Bulletin* 13: 290–296.

KROODSMA, D.A., MAYORGA, J., HOCHBERG, T., ET AL. 2018. Tracking the global footprint of fisheries. *Science* 359: 904–908. doi:10.1126/science.aao5646

LAIST, D.W., KNOWLTON, A.R. & PENDLETON, D. 2014. Effectiveness of mandatory vessel speed limits for protecting North Atlantic Right Whales. *Endangered Species Research* 23: 133–147. doi:10.3354/esr00586

LEWISON, R., HOBDAY, A.J., MAXWELL, S., ET AL. 2015. Dynamic ocean management: Identifying the critical ingredients of dynamic approaches to ocean resource management. *BioScience* 65: 486–498. doi:10.1093/biosci/biv018

LONG, J.A., NELSON, T.A., WEBB, S.L. & GEE, K.L. 2014. A critical examination of indices of dynamic interaction for wildlife telemetry studies. *Journal of Animal Ecology* 83: 1216–1233. doi:10.1111/1365-2656.12198

MAXWELL, S.M., HAZEN, E.L., LEWISON, R.L., ET AL. 2015. Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. *Marine Policy* 58: 42–50. doi:10.1016/j.marpol.2015.03.014

MCCAULEY, D.J., PINSKY, M.L., PALUMBI, S.R., ESTES, J.A., JOYCE, F.H. & WARNER, R.R. 2015. Marine defaunation: Animal loss in the global ocean. *Science* 347: 1255641. doi:10.1126/science.1255641

MOORE, J.E., WALLACE, B.P., LEWISON, R.L., ŽYDELIS, R., COX, T.M. & CROWDER, L.B. 2009. A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management. *Marine Policy* 33: 435–451. doi:10.1016/j.marpol.2008.09.003

ORBEN, R.A., ADAMS, J., HESTER, M., ET AL. 2021. Across borders: External factors and prior behaviour influence North Pacific albatross associations with fishing vessels. *Journal of Applied Ecology* 58: 1272–1283. doi:10.1111/1365-2664.13849

ORO, D., GENOVART, M., TAVECCHIA, G., FOWLER, M.S. & MARTÍNEZ-ABRAÍN, A. 2013. Ecological and evolutionary implications of food subsidies from humans. *Ecology Letters* 16: 1501–1514. doi:10.1111/ele.12187

OSTERBACK, A.-M.K, FRECHETTE, D.M., HAYES, S.A., SHAFFER, S.A. & MOORE, J.W. 2015. Long-term shifts in anthropogenic subsidies to gulls and implications for an imperiled fish. *Biological Conservation* 191: 606–613. doi:10.1016/j.biocon.2015.07.038

PATRICK, S.C., BEARHOP, S., BODEY, T.W., ET AL. 2015. Individual seabirds show consistent foraging strategies in response to predictable fisheries discards. *Journal of Avian Biology* 46: 431–440. doi:10.1111/jav.00660

R CORE TEAM. 2020. *R: A language and environment for statistical computing.* Vienna, Austria: The R Foundation for Statistical Computing.

RIPPLE, W.J., ESTES, J.A., BESCHTA, R.L., ET AL. 2014. Status and ecological effects of the world's largest carnivores. *Science* 343: 1241484. doi:0.1126/science.1241484

ROCKWOOD, R.C., ADAMS, J.D., HASTINGS, S., MORTEN, J. & JAHNCKE, J. 2021. Modeling whale deaths from vessel strikes to reduce the risk of fatality to endangered whales. *Frontiers in Marine Science* 8: 649890. doi:10.3389/fmars.2021.649890

ROCKWOOD, R.C., ADAMS, J., SILBER, G. & JAHNCKE, J. 2020. Estimating effectiveness of speed reduction measures for decreasing whale-strike mortality in a high-risk region. *Endangered Species Research* 43: 145–166. doi:10.3354/esr01056

ROCKWOOD, R.C., CALAMBOKIDIS, J. & JAHNCKE, J. 2017. High mortality of Blue, Humpback and Fin whales from modeling of vessel collisions on the US West Coast suggests population impacts and insufficient protection. *PLoS One* 12: e0183052. doi:10.1371/journal.pone.0183052

SAEZ, L., LAWSON, D. & DEANGELIS, M. 2021. *Large whale entanglements off the US West Coast, from 1982–2017*. NOAA Technical Memorandum NMFS-OPR-63A. Washington, USA: National Oceanic and Atmospheric Administration.

SAMHOURI, J.F., FEIST, B.E., FISHER, M.C., ET AL. 2021. Marine heatwave challenges solutions to human–wildlife conflict. *Proceedings of the Royal Society B* 288: 20211607. doi:10.1098/rspb.2021.1607

SANTORA, J.A., MANTUA, N.J., SCHROEDER, I.D., ET AL. 2020. Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. *Nature Communications* 11: 536. doi:10.1038/s41467-019-14215-w

SARÀ, M., FIRMAMENTO, R., CANGEMI, G., ET AL. 2023. Welcome aboard: Are birds migrating across the Mediterranean Sea using ships as stopovers during adverse weather conditions? *International Journal of Avian Science* 165: 328–339. doi:10.1111/ibi.13103

SCHUMMER, M.L. & EDDLEMAN, W.R. 2003. Effects of disturbance on activity and energy budgets of migrating waterbirds in south-central Oklahoma. *The Journal of Wildlife Management* 67: 789–795.

SCHWEMMER, P., MENDEL, B., SONNTAG, N., DIERSCHKE, V. & GARTHE, S. 2011. Effects of ship traffic on seabirds in offshore waters: Implications for marine conservation and spatial planning. *Ecological Applications* 21: 1851–1860.

SHAFFER, S.A., COCKERHAM, S., WARZYBOK, P., ET AL. 2017. Population-level plasticity in foraging behavior of Western Gulls (*Larus occidentalis*). *Movement Ecology* 5: 27. doi:10.1186/s40462-017-0118-9

SHERLEY, R.B., LADD-JONES, H., GARTHE, S., STEVENSON, O. & VOTIER, S.C. 2020. Scavenger communities and fisheries waste: North Sea discards support 3 million seabirds, 2 million fewer than in 1990. *Fish and Fisheries* 21: 132–145. doi:10.1111/faf.12422

SILVA, T.L., POWERS, K.D., ROBBINS, J., ET AL. 2022. Exploring the use of seabirds as a dynamic ocean management tool to mitigate anthropogenic risk to large whales. *Frontiers in Marine Science* 9: 837604. doi:10.3389/fmars.2022.837604

SPEAR, L.B. 1988. Dispersal patterns of Western Gulls from southeast Farallon Island. *The Auk* 105: 128–141.

THOMPSON, A.R., SCHROEDER, I.D., BOGRAD, S.J., ET AL. 2019. State of the California Current 2018–19: A novel anchovy regime and a new marine heatwave? *California Cooperative Oceanic Fisheries Investigations Reports* 60: 1–65.

USCG (UNITED STATES COAST GUARD). 2015. *AIS Requirements*. Washington, USA: Navigation Center, USCG. [Accessed at https://www.navcen.uscg.gov/ais-requirements on 05 June 2023.]

USCG. 2017. *Merchant Vessels of the United States*. Washington, USA: USCG. [Accessed at https://www.dco.uscg.mil/Our-Organization/Assistant-Commandant-for-Prevention-Policy-CG-5P/Inspections-Compliance-CG-5PC-/Office-of-Investigations-Casualty-Analysis/Merchant-Vessels-of-the-United-States/ on 05 June 2023.]

VALDIVIA, A., WOLF, S. & SUCKLING, K. 2019. Marine mammals and sea turtles listed under the US Endangered Species Act are recovering. *PLoS One* 14: e0210164. doi:10.1371/journal.pone.0210164

VAN DER HOOP, J.M., VANDERLAAN, A.S.M., COLE, T.V.N., ET AL. 2015. Vessel strikes to large whales before and after the 2008 ship strike rule. *Conservation Letters* 8: 24–32. doi:10.1111/conl.12105

VEIT, R.R. & HARRISON, N.M. 2017. Positive interactions among foraging seabirds, marine mammals and fishes and implications for their conservation. *Frontiers in Ecology and Evolution* 5: 121. doi:10.3389/fevo.2017.00121

VOTIER, S.C., BEARHOP, S., WITT, M.J., INGER, R., THOMPSON D. & NEWTON, J. 2010. Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. *Journal of Applied Ecology* 47: 487–497. doi:10.1111/j.1365-2664.2010.01790.x

WEIMERSKIRCH, H., COLLET, J., CORBEAU, A., ET AL. 2020. Ocean sentinel albatrosses locate illegal vessels and provide the first estimate of the extent of nondeclared fishing. *Proceedings of the National Academy of Sciences* 117: 3006–3014. doi:10.1073/pnas.1915499117

WEIMERSKIRCH, H., FILIPPI, D.P., COLLET, J., WAUGH, S.M. & PATRICK, S.C. 2018. Use of radar detectors to track attendance of albatrosses at fishing vessels. *Conservation Biology* 32: 240–245. doi:10.1111/cobi.12965

WELLS, B.K., SCHROEDER, I.D., BOGRAD, S.J., ET AL. 2017. State of the California Current 2016–17: Still anything but “normal” in the north. *California Cooperative Oceanic Fisheries Investigations Reports* 58: 1–55.